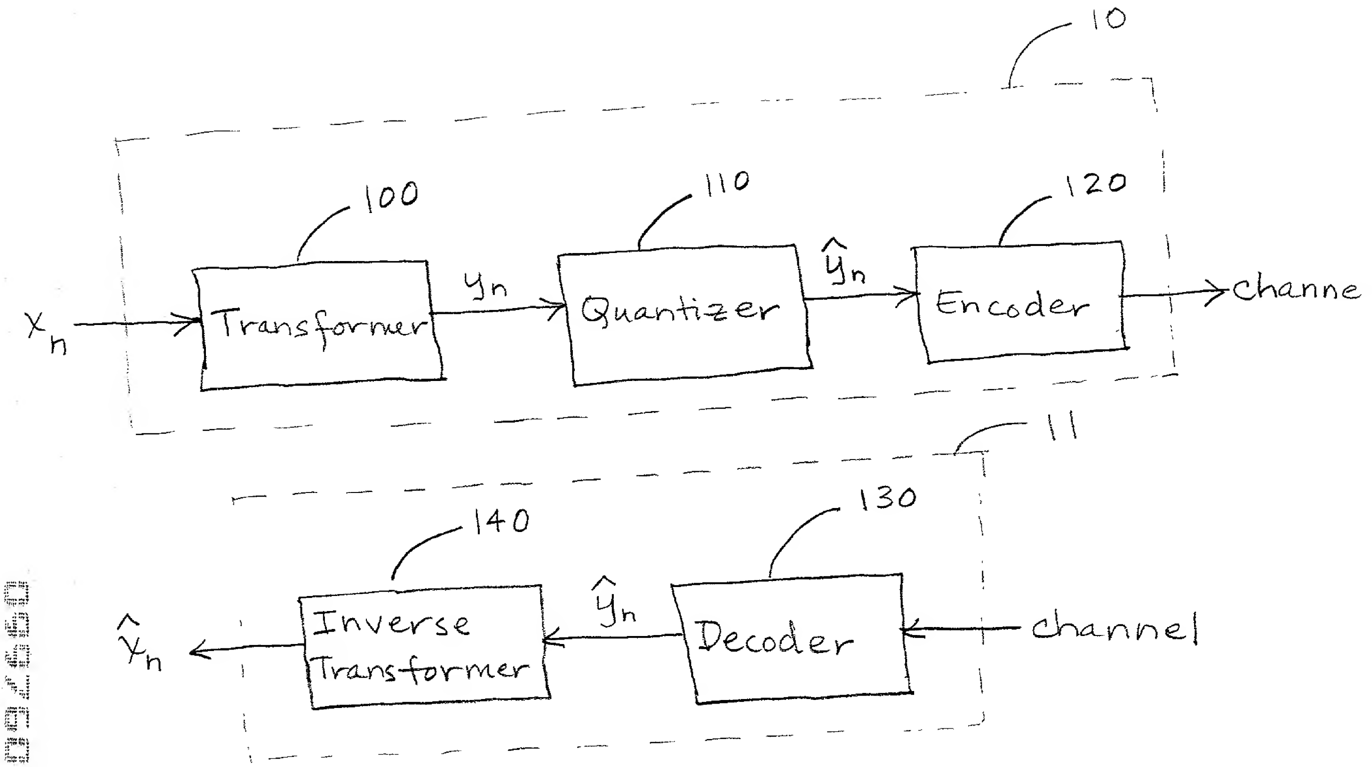

10
100
110
120
x_n
Transformer
y_n
Quantizer
$\hat{y}_n$
Encoder
channel
11
140
130
$\hat{x}_n$
Inverse Transformer
$\hat{y}_n$
Decoder
channel

Fig 1

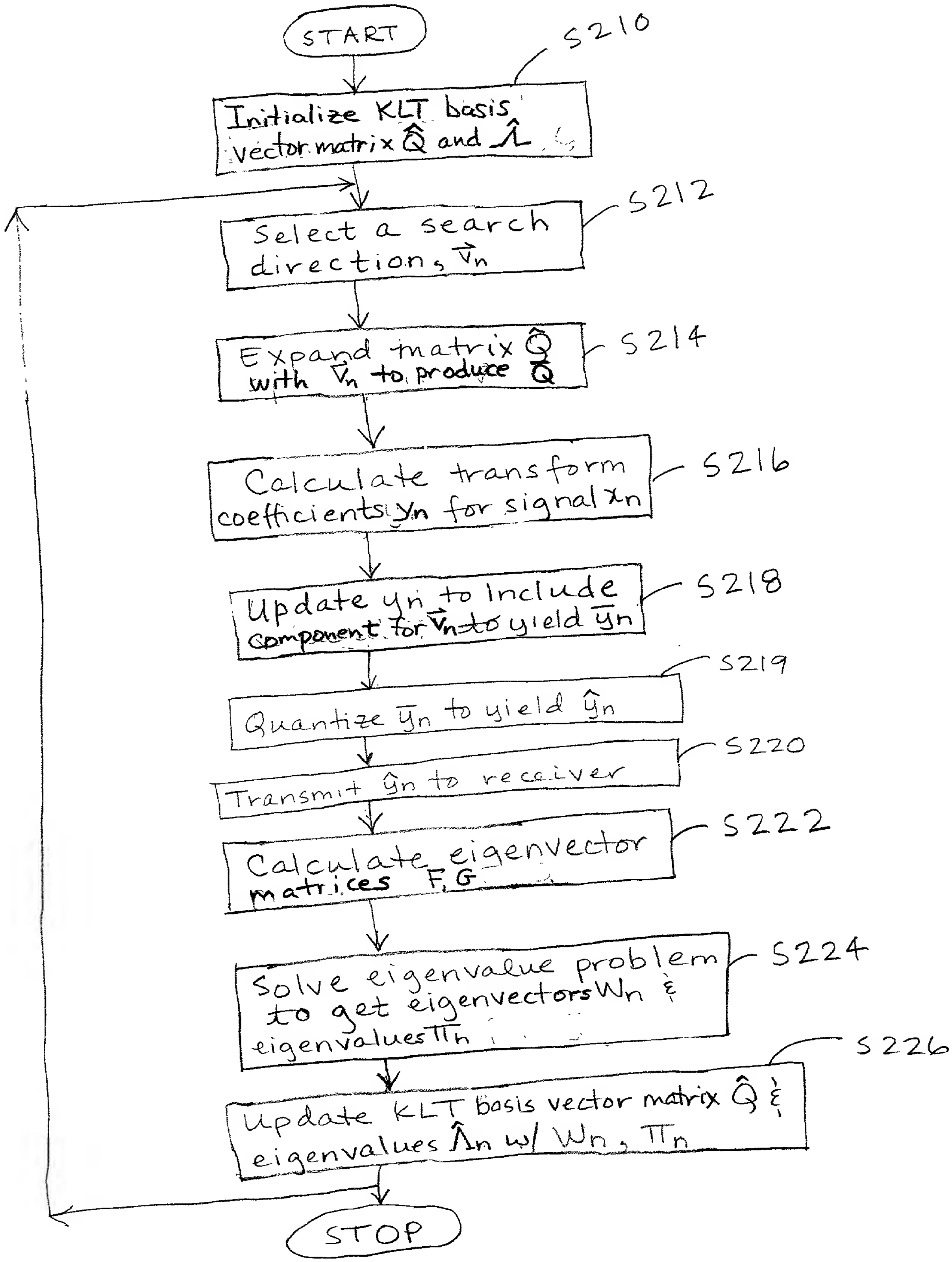

START
S210
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
S212
Select a search direction, $\vec{v}_n$
S214
Expand matrix $\hat{Q}$ with $\vec{v}_n$ to produce $\bar{Q}$
S216
Calculate transform coefficients y_n for signal x_n
S218
Update y_n to include component for $\vec{v}_n$ to yield $\bar{y}_n$
S219
Quantize $\bar{y}_n$ to yield $\hat{y}_n$
S220
Transmit $\hat{y}_n$ to receiver
S222
Calculate eigenvector matrices F, G
S224
Solve eigenvalue problem to get eigenvectors W_n & eigenvalues Π_n
S226
Update KLT basis vector matrix $\hat{Q}$ & eigenvalues $\hat{\Lambda}_n$ w/ W_n, Π_n
STOP

Fig 2A

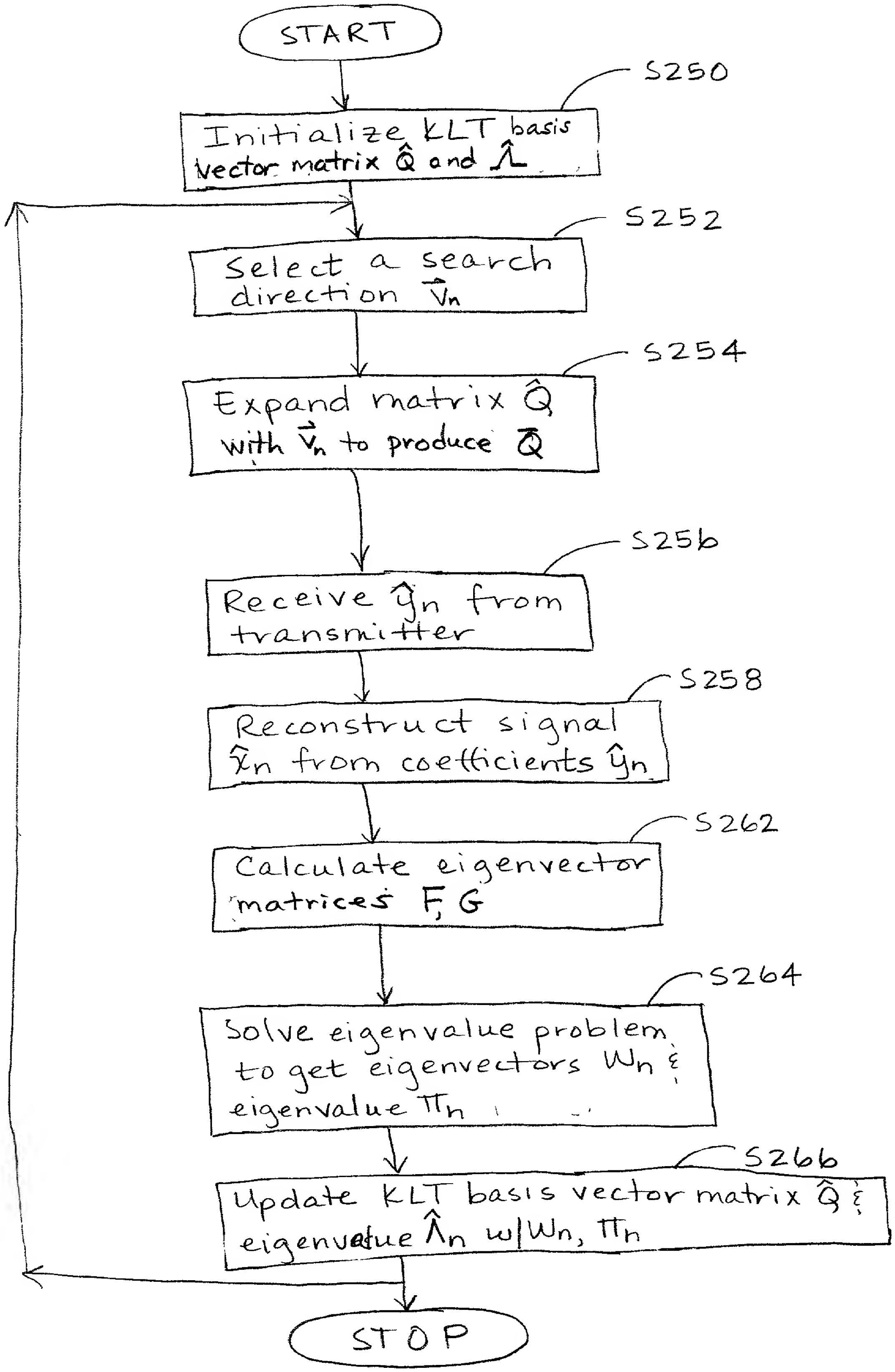

START
S250
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
S252
Select a search direction $\vec{v}_n$
S254
Expand matrix $\hat{Q}$ with $\vec{v}_n$ to produce $\bar{Q}$
S256
Receive $\hat{y}_n$ from transmitter
S258
Reconstruct signal $\hat{x}_n$ from coefficients $\hat{y}_n$
S262
Calculate eigenvector matrices F, G
S264
Solve eigenvalue problem to get eigenvectors W_n & eigenvalue Π_n
S266
Update KLT basis vector matrix $\hat{Q}$ & eigenvalue $\hat{\Lambda}_n$ w/ W_n, Π_n
STOP

Fig 2B

transmitter

$\hat{Q}_0 = I_N(:,1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

$\quad \bar{Q}_n = [\hat{Q}_{n-1} \;\; v_n]$

$\quad y_n = \hat{Q}_{n-1}^T x_n$

$\quad \bar{y}_n = [y_n^T \;\; x_n^T v_n]^T$

$\quad \hat{y}_n = \Delta(\bar{y}_n)$

$\quad$ transmit $\hat{y}_n$ to receiver

$\quad F = \gamma \bar{Q}_n^T \hat{Q}_{n-1} \Lambda_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

$\quad G = \bar{Q}_n^T \bar{Q}_n$

$\quad$ solve $F W_n = G W_n \Pi_n$ for W_n, Π_n

$\quad \hat{Q}_n = \bar{Q}_n W_n(:,1:r)$

$\quad \hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

end

receiver

$\hat{Q}_0 = I_N(:,1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

$\quad \bar{Q}_n = [\hat{Q}_{n-1} \;\; v_n]$

$\quad$ wait for $\hat{y}_n$

$\quad \hat{x}_n = \hat{Q}_{n-1} \hat{y}_n(1:r)$

$\quad F = \gamma \bar{Q}_n^T \hat{Q}_{n-1} \hat{\Lambda}_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

$\quad G = \bar{Q}_n^T \bar{Q}_n$

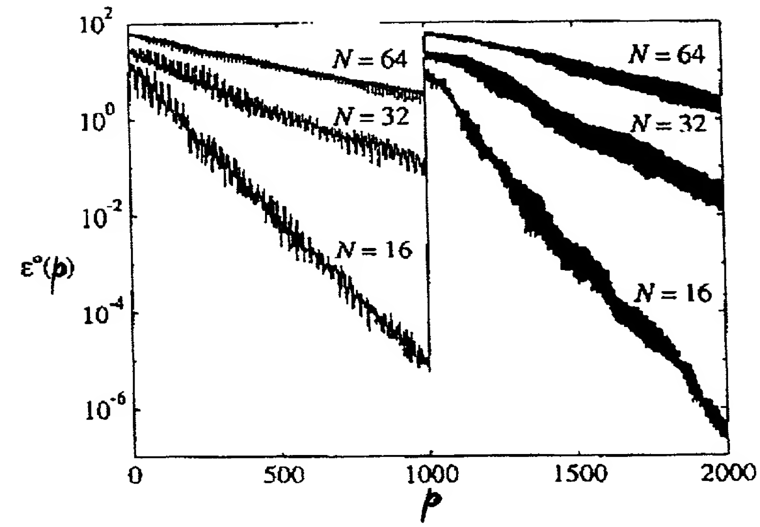
$\quad$ solve $F W_n = G W_n \Pi_n$ for W_n, Π_n

$\quad \hat{Q}_n = \bar{Q}_n W_n(:,1:r)$

$\quad \hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

end

Figure 2c



10^2
10^0
10^{-2}
10^{-4}
10^{-6}
$\varepsilon^o(p)$
$N = 64$
$N = 32$
$N = 16$
$N = 64$
$N = 32$
$N = 16$
0
500
1000
1500
2000
p

Fig 3

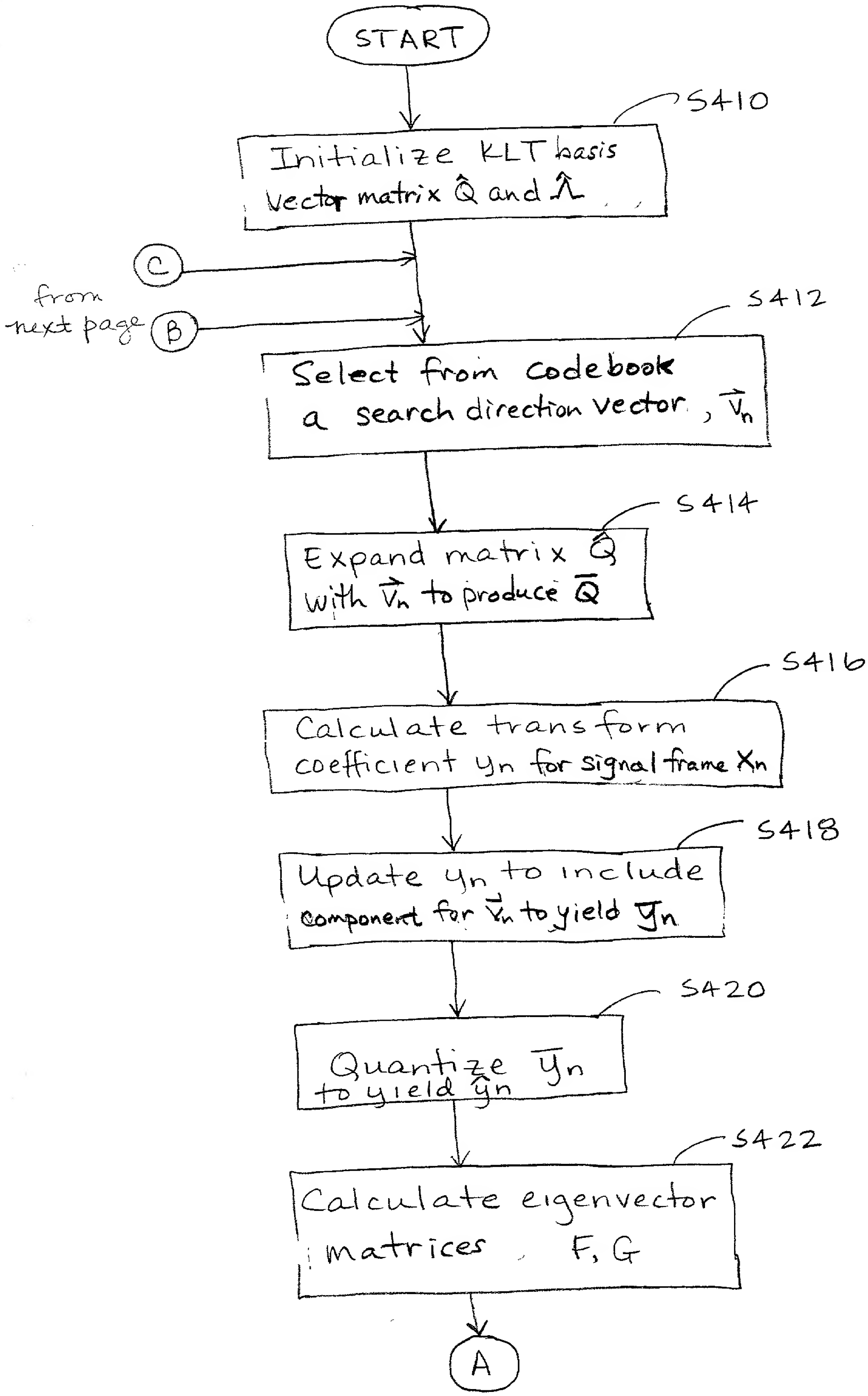

START
S410
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
C
from next page
B
S412
Select from codebook a search direction vector, $\vec{v}_n$
S414
Expand matrix $\hat{Q}$ with $\vec{v}_n$ to produce $\bar{Q}$
S416
Calculate transform coefficient y_n for signal frame x_n
S418
Update y_n to include component for $\vec{v}_n$ to yield $\bar{y}_n$
S420
Quantize $\bar{y}_n$ to yield $\hat{y}_n$
S422
Calculate eigenvector matrices F, G
A

Fig 4A

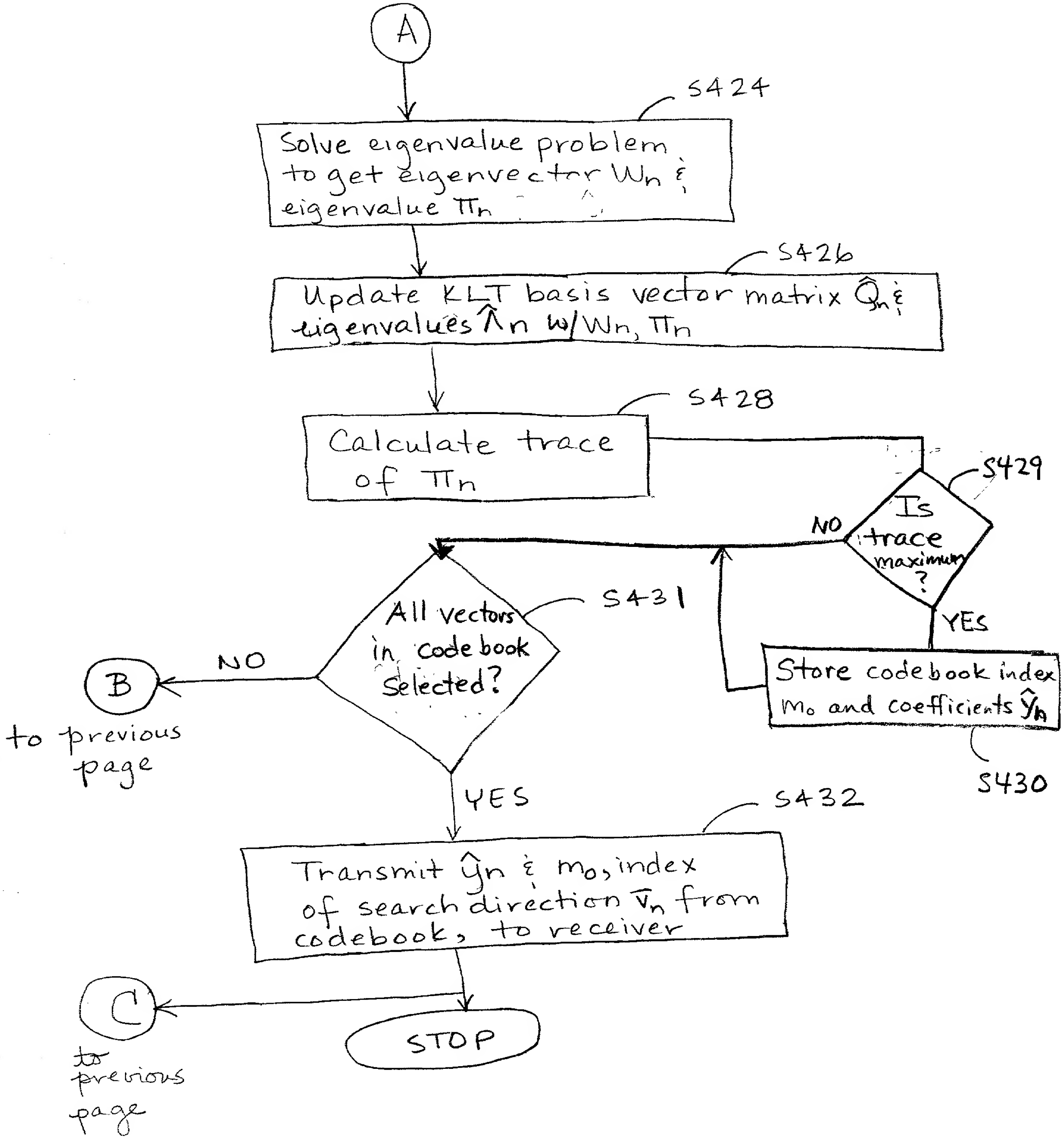

A
S424
Solve eigenvalue problem to get eigenvector Wn & eigenvalue Πn
S426
Update KLT basis vector matrix Q̂n & eigenvalues Λ̂n w/ Wn, Πn
S428
Calculate trace of Πn
S429
Is trace maximum?
NO
YES
S430
Store codebook index m0 and coefficients ŷn
S431
All vectors in code book selected?
NO
B
to previous page
YES
S432
Transmit ŷn & m0, index of search direction v̄n from codebook, to receiver
C
to previous page
STOP

Fig 4A (CONT.)

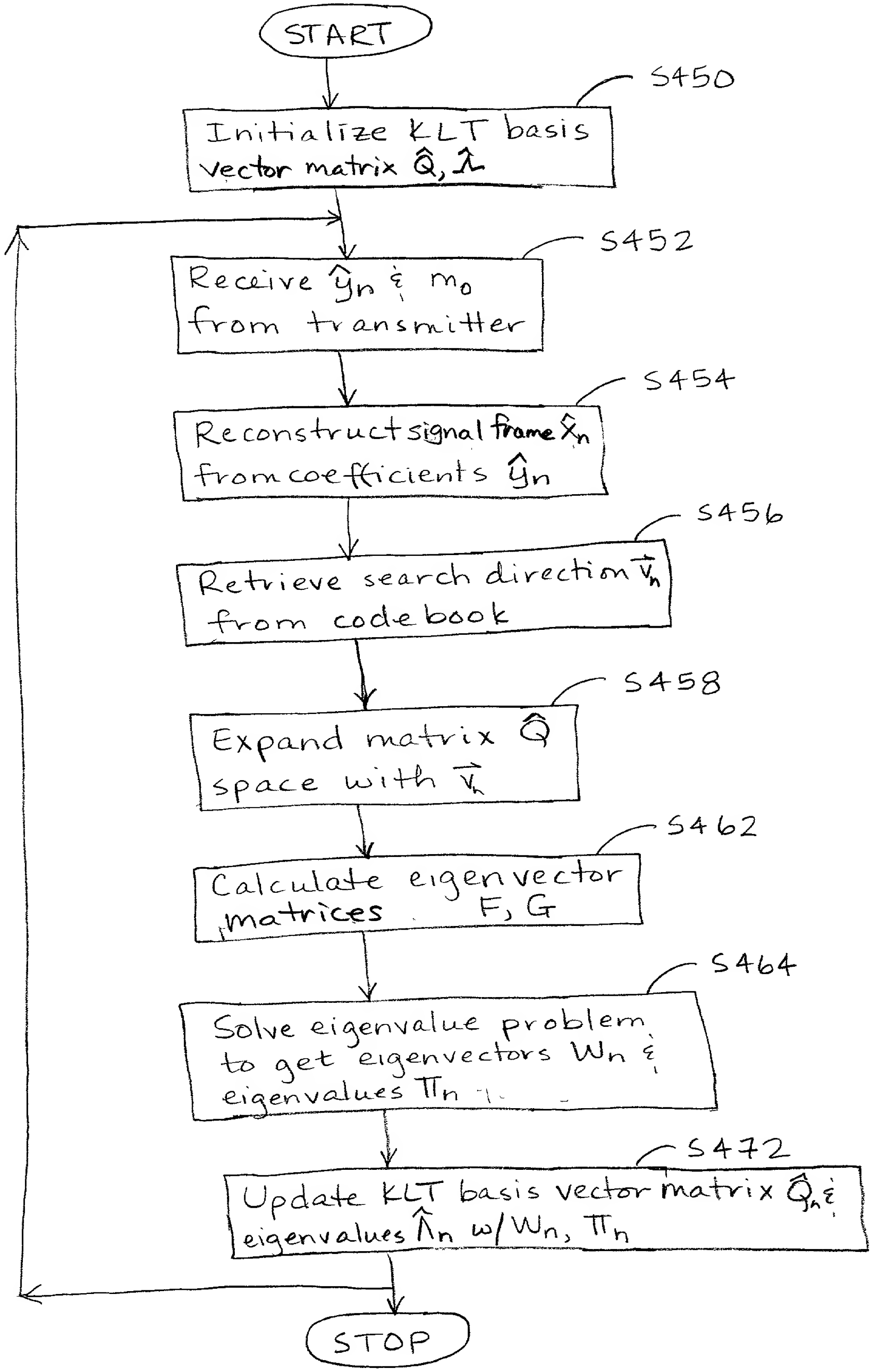

START
S450
Initialize KLT basis vector matrix $\hat{Q}, \hat{\Lambda}$
S452
Receive $\hat{y}_n$ & m_0 from transmitter
S454
Reconstruct signal frame $\hat{x}_n$ from coefficients $\hat{y}_n$
S456
Retrieve search direction $\vec{v}_n$ from code book
S458
Expand matrix $\hat{Q}$ space with $\vec{v}_n$
S462
Calculate eigenvector matrices F, G
S464
Solve eigenvalue problem to get eigenvectors W_n & eigenvalues Π_n
S472
Update KLT basis vector matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$ w/ W_n, Π_n
STOP

Fig 4B

Figure 4C

transmitter

$\hat{Q}_0 = I_N(:,1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

    $T_{max} = 0$

    for $m = 1, \ldots, M$

        $v_n = V(:, m)$

        $\bar{Q} = [\hat{Q}_{n-1} \;\; v_n]$

        $y_n = \hat{Q}_{n-1}^T x_n$

        $\bar{y}_n = [y_n^T \;\; x_n^T v_n]^T$

        $\hat{y}_n = \Delta(\bar{y}_n)$

        $F = \gamma \bar{Q}^T \hat{Q}_{n-1} \hat{\Lambda}_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

        $G = \bar{Q}_n^T \bar{Q}_n$

        solve $FW_n = GW_n\Pi_n$ for W_n, Π_n

        $\hat{Q}_n = \bar{Q}_n W_n(:,1:r)$

        $\hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

        $T = \mathrm{trace}(\Pi_n(1:r, 1:r))$

        if $T > T_{max}$

            $T_{max} = T$

            $m_0 = m$

            $\hat{y}_n^* = \hat{y}_n$

        end

    end

    $\hat{y}_n = \hat{y}_n^*$

    transmit $\hat{y}_n$, m_0 to receiver

end

receiver

$\hat{Q}_0 = I_N(:,1:r)$

$\hat{\Lambda}_0 = I_r$

for $n = 1, 2, \ldots$

    wait for $\hat{y}_n$, m_0

    $\hat{x}_n = \hat{Q}_{n-1} \hat{y}_n(1:r)$

    $v_n = V(:, m_0)$

    $\bar{Q}_n = [\hat{Q}_{n-1} \;\; v_n]$

    $F = \gamma \bar{Q}^T \hat{Q}_{n-1} \hat{\Lambda}_{n-1} \hat{Q}_{n-1}^T \bar{Q}_n + \hat{y}_n \hat{y}_n^T$

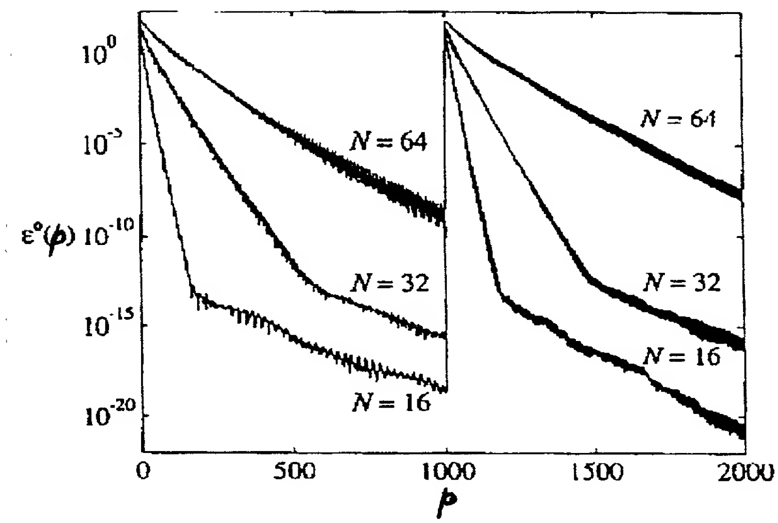
    $G = \bar{Q}_n^T \bar{Q}_n$

    solve $FW_n = GW_n\Pi_n$ for W_n, Π_n

    $\hat{Q}_n = \bar{Q}_n W_n(:,1:r)$

    $\hat{\Lambda}_n = \Pi_n(1:r, 1:r)$

end



10^{0}
10^{-5}
$\varepsilon^{o}(p)$ 10^{-10}
10^{-15}
10^{-20}
$N = 64$
$N = 32$
$N = 16$
$N = 64$
$N = 32$
$N = 16$
0
500
1000
1500
2000
p

Fig 5

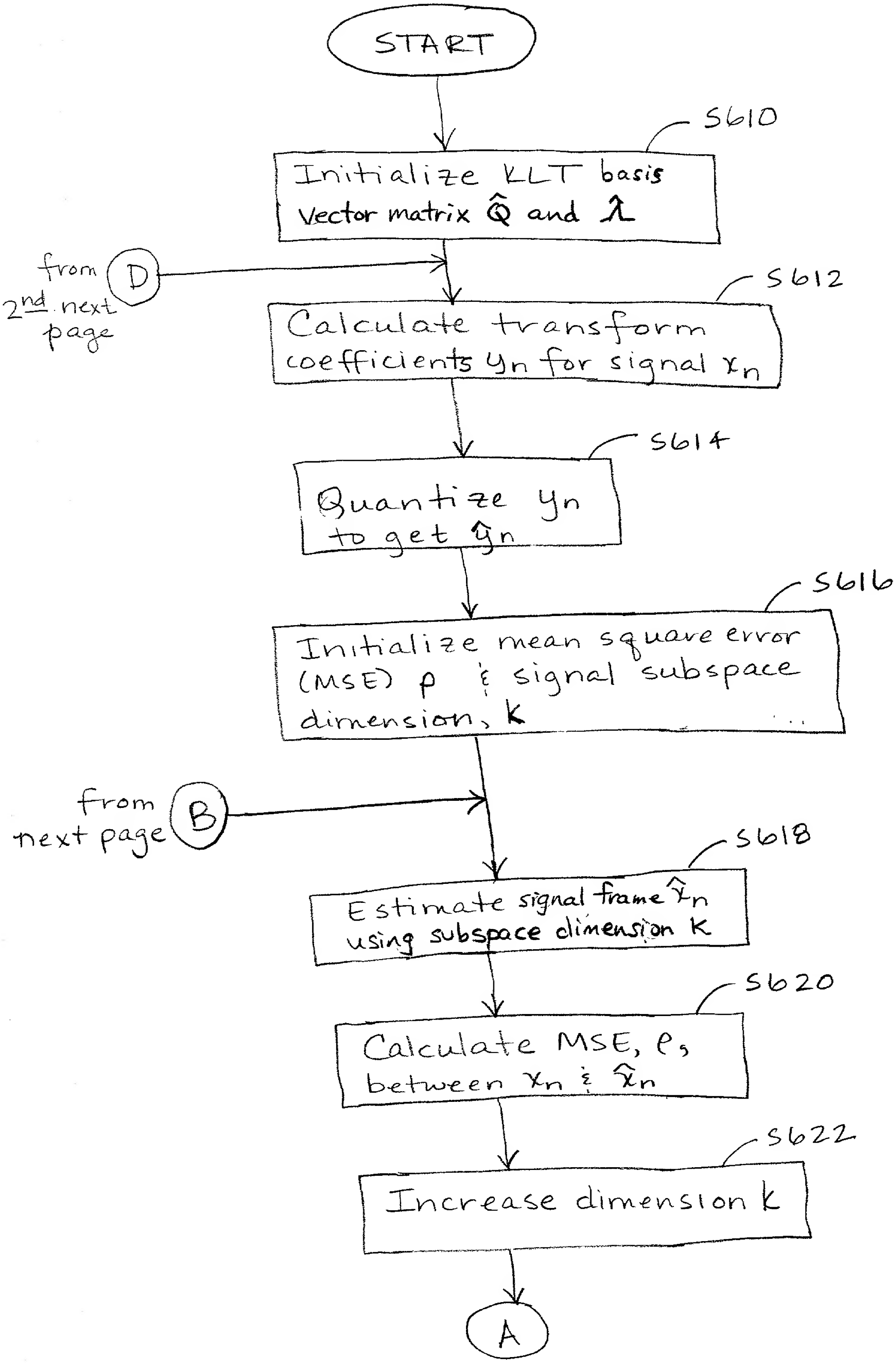

START
S610
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\lambda}$
from 2nd next page
D
S612
Calculate transform coefficients y_n for signal x_n
S614
Quantize y_n to get $\hat{y}_n$
S616
Initialize mean square error (MSE) ρ & signal subspace dimension, k
from next page
B
S618
Estimate signal frame $\hat{x}_n$ using subspace dimension k
S620
Calculate MSE, ρ, between x_n & $\hat{x}_n$
S622
Increase dimension k
A

Fig 6A

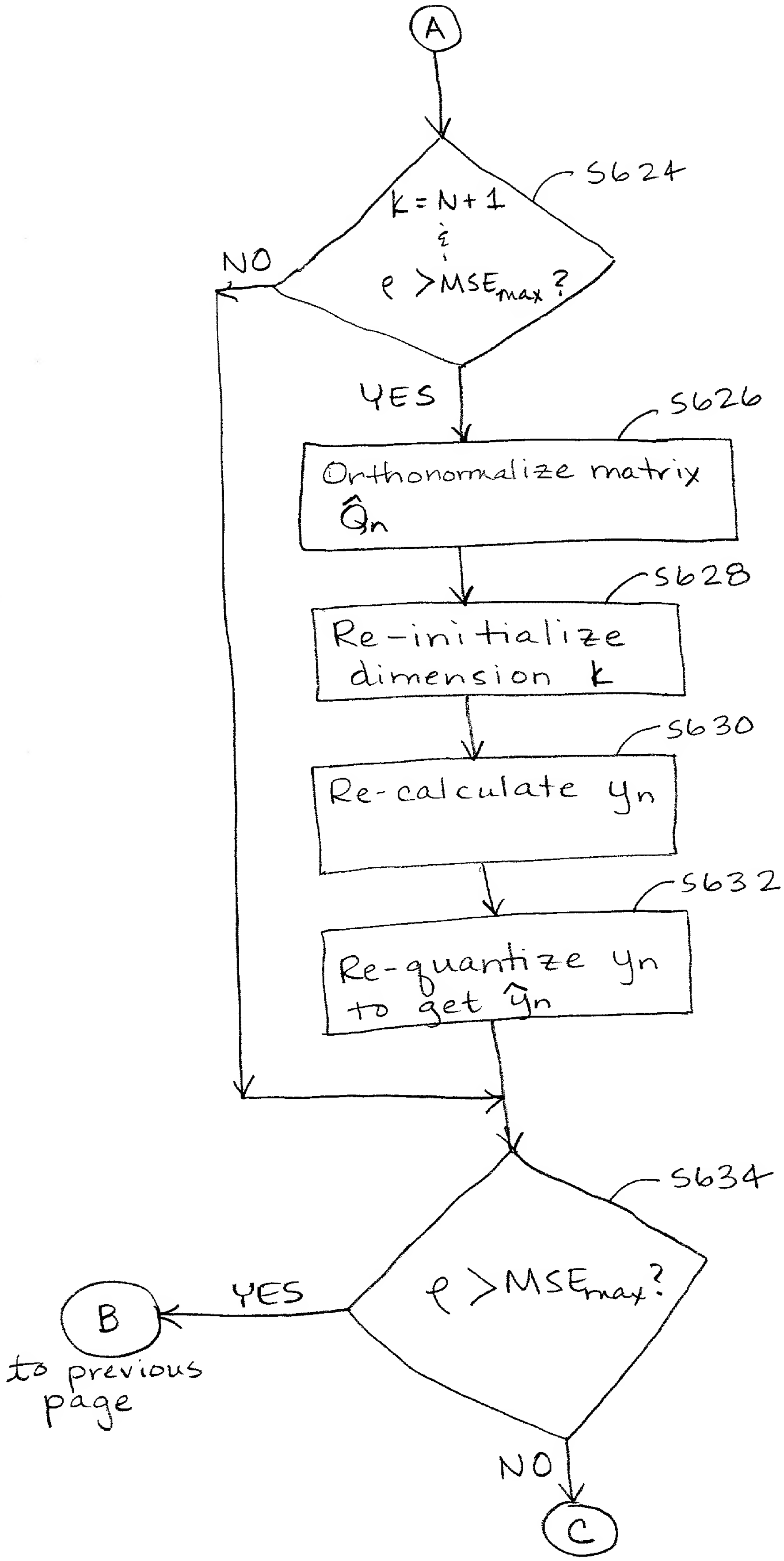

A
S624
k = N+1
¿
e > MSE_max ?
NO
YES
S626
Orthonormalize matrix Q̂n
S628
Re-initialize dimension k
S630
Re-calculate yn
S632
Re-quantize yn to get ŷn
S634
e > MSE_max ?
YES
B
to previous page
NO
C

Fig 6A (CONT.)

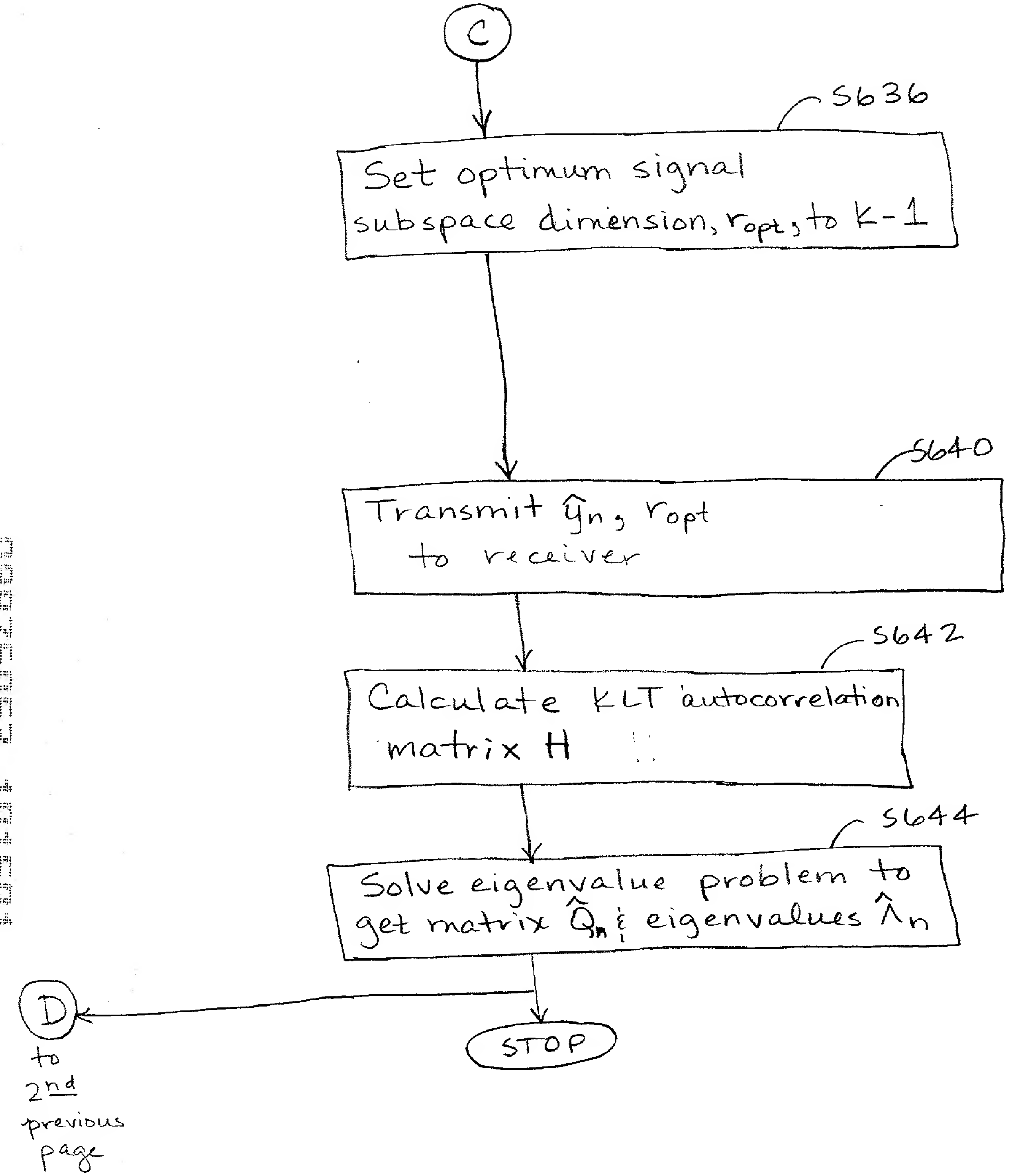

C
S636
Set optimum signal subspace dimension, r_{opt}, to K-1
S640
Transmit $\hat{y}_n$, r_{opt} to receiver
S642
Calculate KLT autocorrelation matrix H
S644
Solve eigenvalue problem to get matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$
D
to 2nd previous page
STOP

Fig 6A (CONT.)

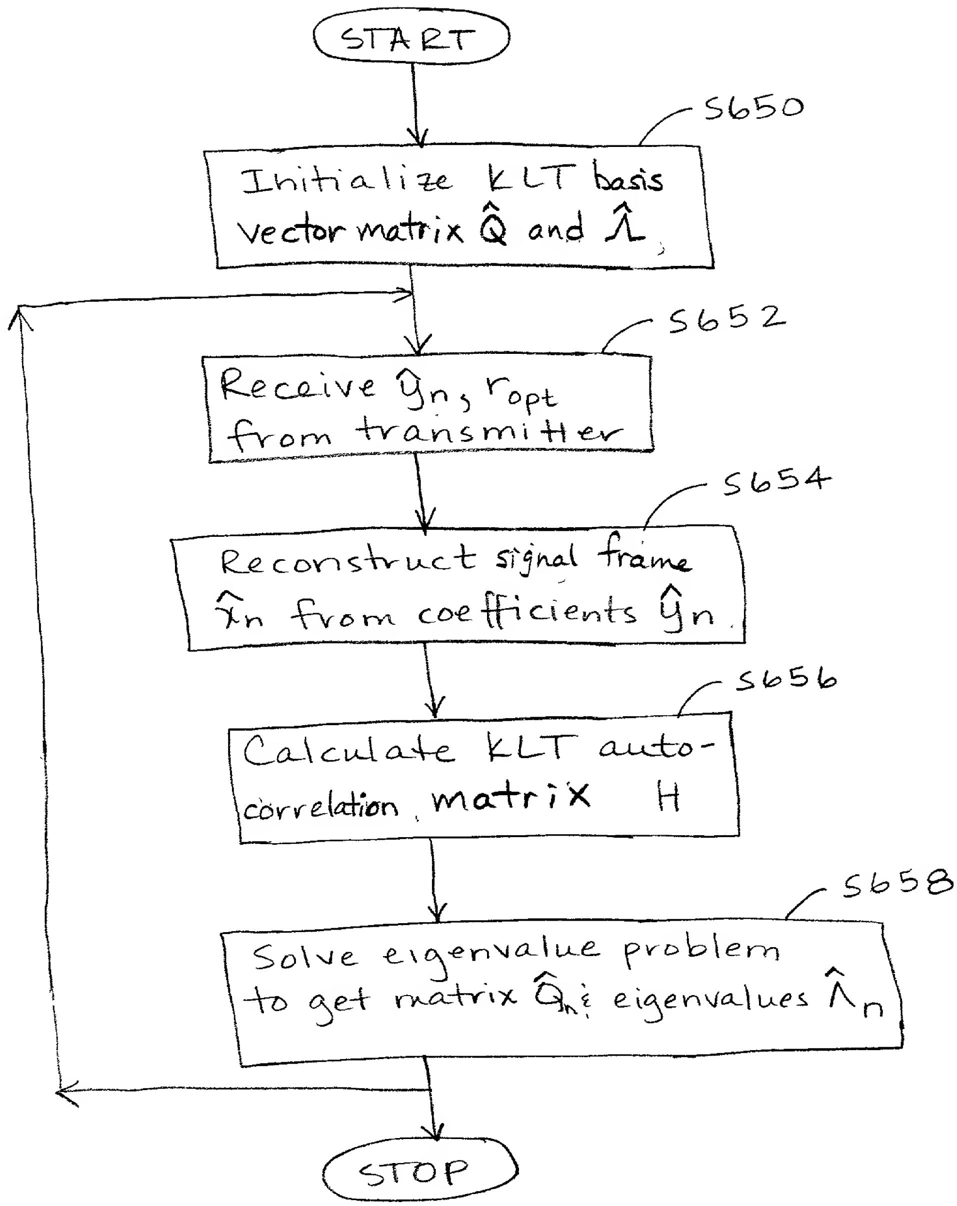

START
S650
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{\Lambda}$
S652
Receive $\hat{y}_n$, r_{opt} from transmitter
S654
Reconstruct signal frame $\hat{x}_n$ from coefficients $\hat{y}_n$
S656
Calculate KLT auto-correlation matrix H
S658
Solve eigenvalue problem to get matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$
STOP

Fig 6B

transmitter

$\hat{Q}_0 = I_N$

$\hat{\Lambda}_0 = I_N$

for $n = 1, 2, \ldots$

  $y_n = \hat{Q}_{n-1}^T x_n$

  $\hat{y}_n = \Delta(y_n)$

  $\rho = 1$

  $k = 1$

  while $\rho > MSE_{max}$

    $\hat{x}_n = \hat{Q}_{n-1}(:, 1:k)\, \hat{y}_n(1:k);$

    $\rho = \| \hat{x}_n - x_n \|^2 / \| x_n \|^2$

    $k = k + 1$

    if $k = N+1$ and $\rho > MSE_{max}$

      orthonormalize columns of $\hat{Q}_n$

      $k = 1$

      $y_n = \hat{Q}_{n-1}^T x_n$

      $\hat{y}_n = \Delta(y_n)$

    end

  end

  $r_{opt} = k - 1$

  transmit $\hat{y}_n(1:r_{opt})$, r_{opt} to receiver

  $H = \gamma \hat{\Lambda}_{n-1} + \hat{y}_n \hat{y}_n^T$

  solve $H\hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$

end

receiver

$\hat{Q}_0 = I_N$

$\hat{\Lambda}_0 = I_N$

for $n = 1, 2, \ldots$

  wait for $\hat{y}_n(1:r_{opt})$, r_{opt}

  $\hat{x}_n = \hat{Q}_{n-1}(:, 1:r_{opt})\, \hat{y}_n(1:r_{opt})$

  $H = \gamma \hat{\Lambda}_{n-1} + \hat{y}_n \hat{y}_n^T$

  solve $H\hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$

end

Figure 6C

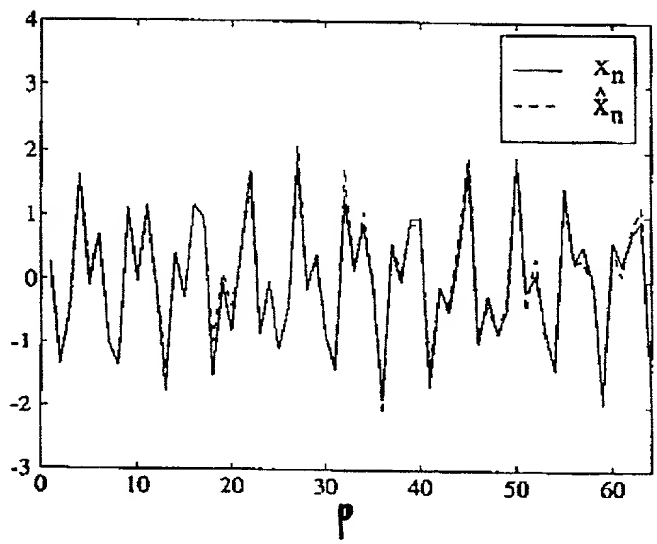


Fig 7

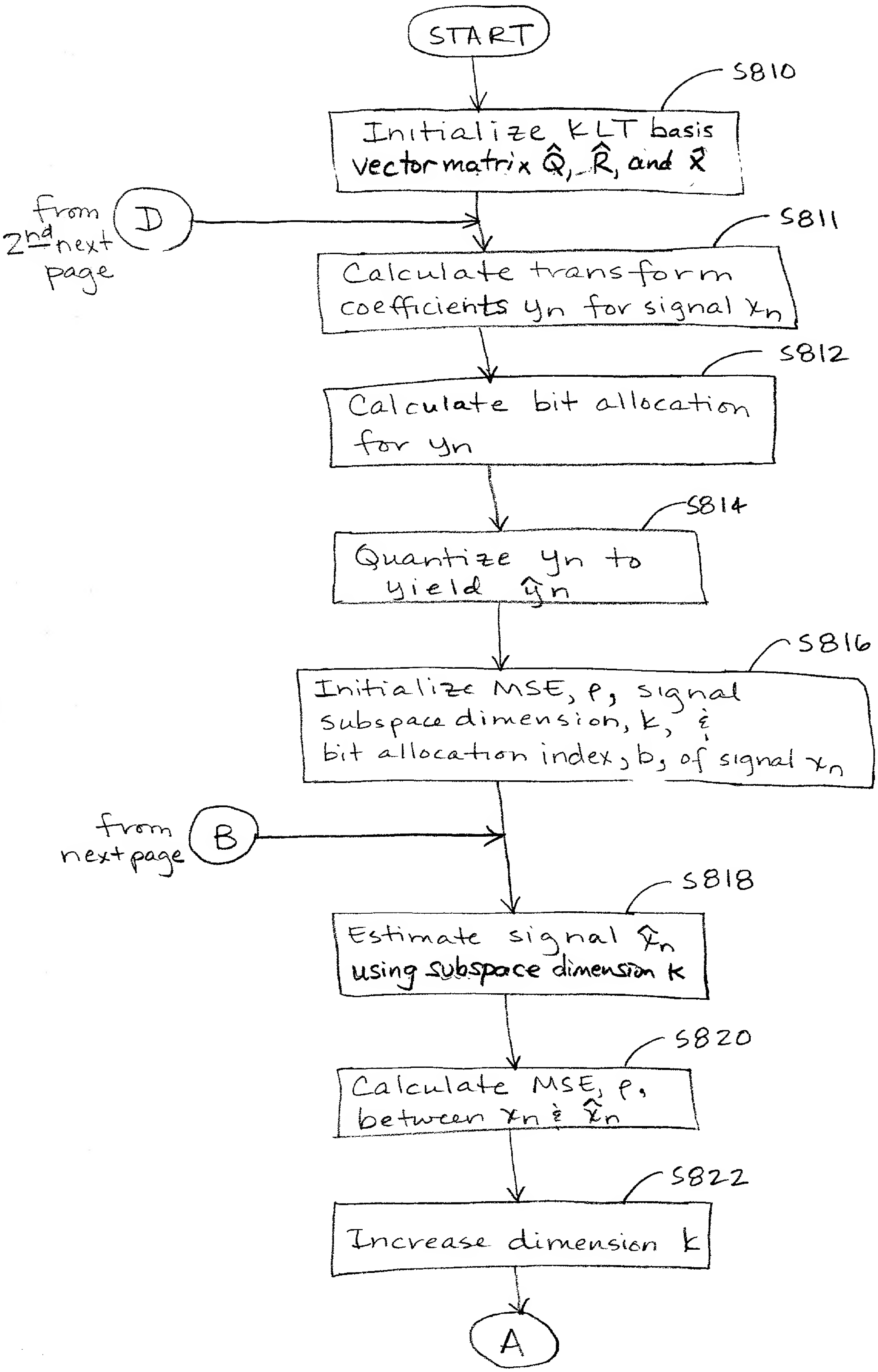

START
S810
Initialize KLT basis vector matrix $\hat{Q}$, $\hat{R}$, and $\hat{x}$
from 2nd next page
D
S811
Calculate transform coefficients y_n for signal x_n
S812
Calculate bit allocation for y_n
S814
Quantize y_n to yield $\hat{y}_n$
S816
Initialize MSE, ρ, signal subspace dimension, k, & bit allocation index, b, of signal x_n
from next page
B
S818
Estimate signal $\hat{x}_n$ using subspace dimension k
S820
Calculate MSE, ρ, between x_n & $\hat{x}_n$
S822
Increase dimension k
A

Fig 8A

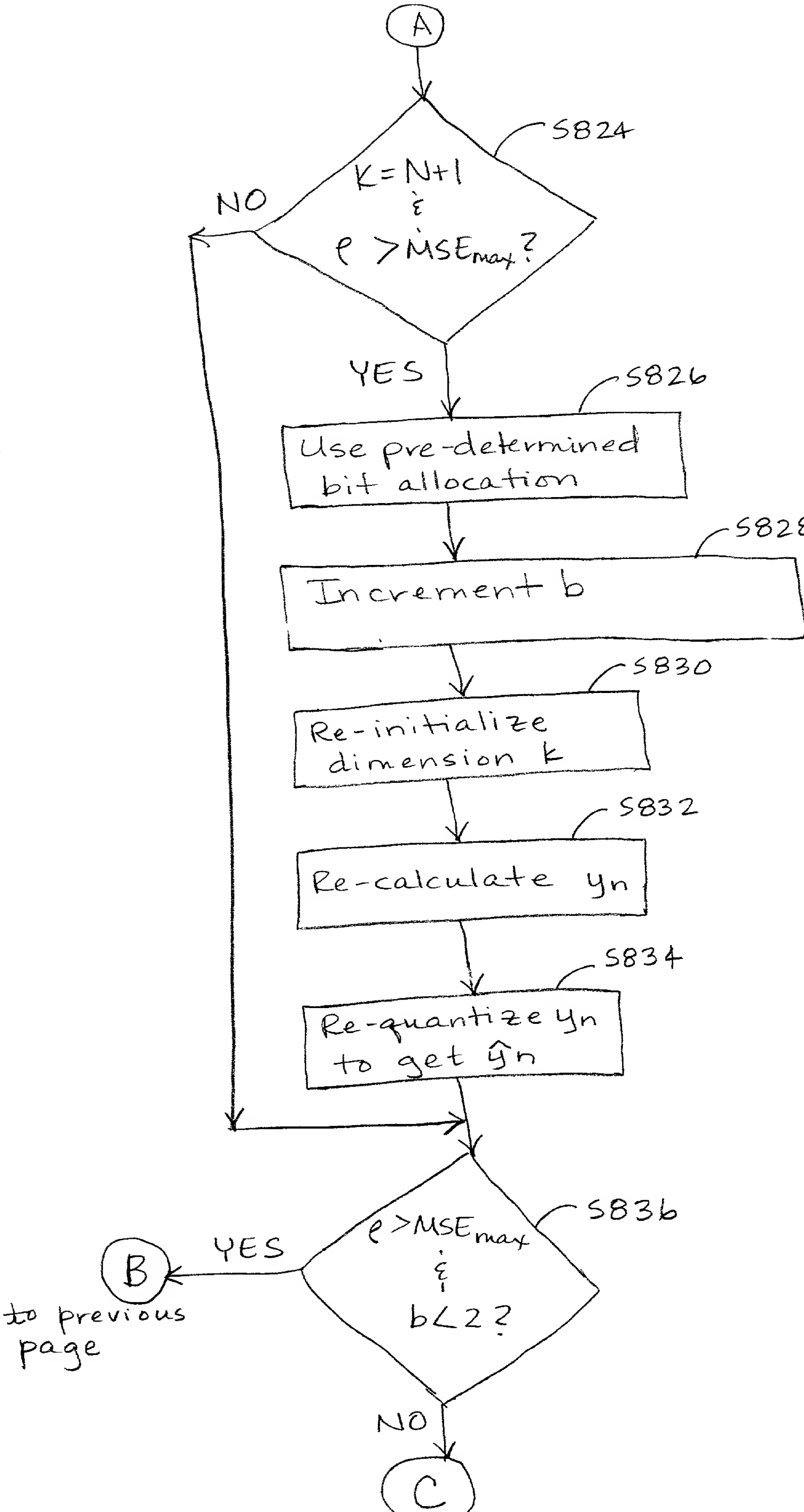
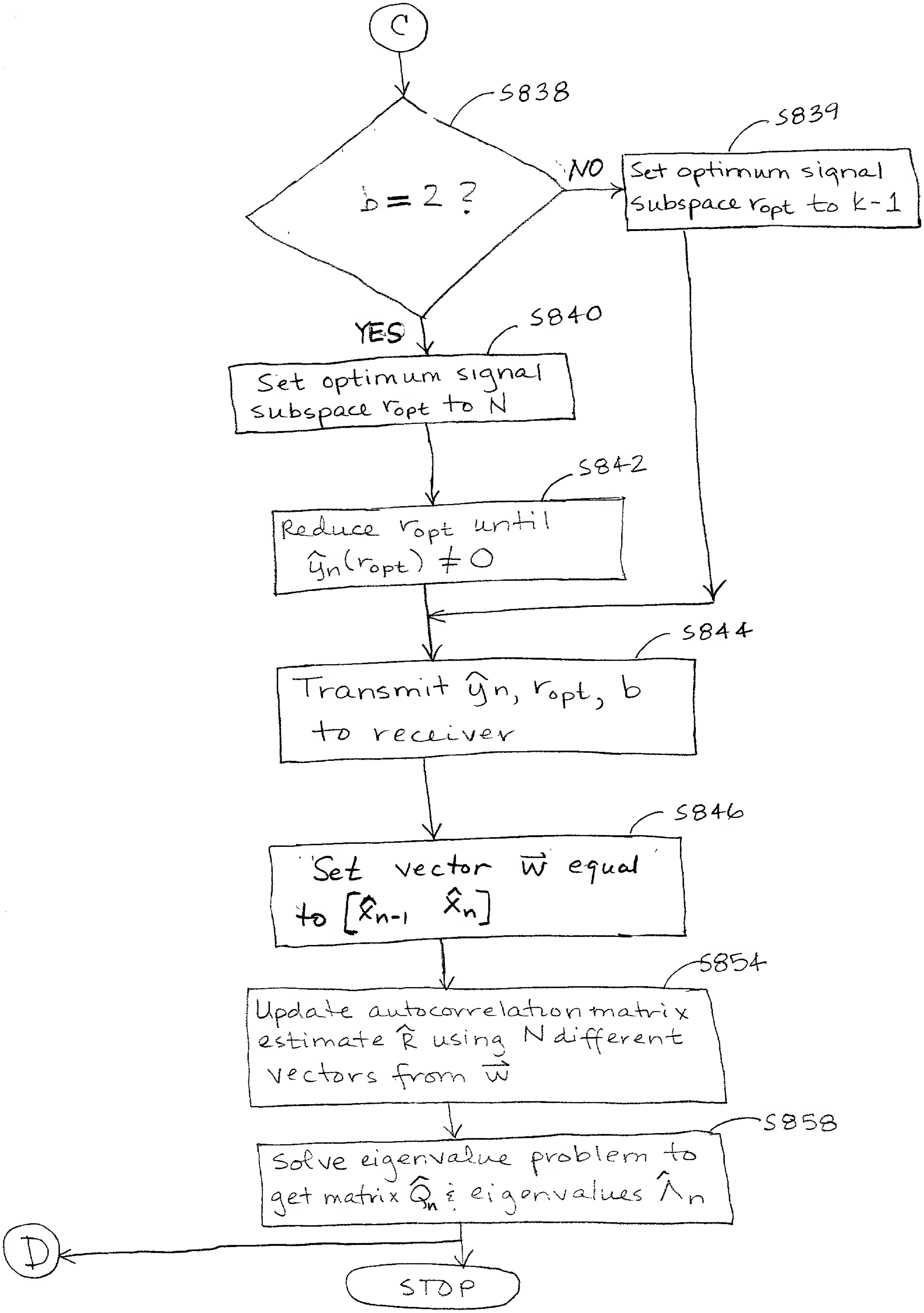

A
S824
K=N+1
&
ρ > MSEmax?
NO
YES
S826
Use pre-determined bit allocation
S828
Increment b
S830
Re-initialize dimension k
S832
Re-calculate yn
S834
Re-quantize yn to get ŷn
S836
ρ > MSEmax
&
b < 2?
YES
B
to previous page
NO
C

Fig 8A (CONT.)



to 2nd previous page

Fig 8A (CONT.)

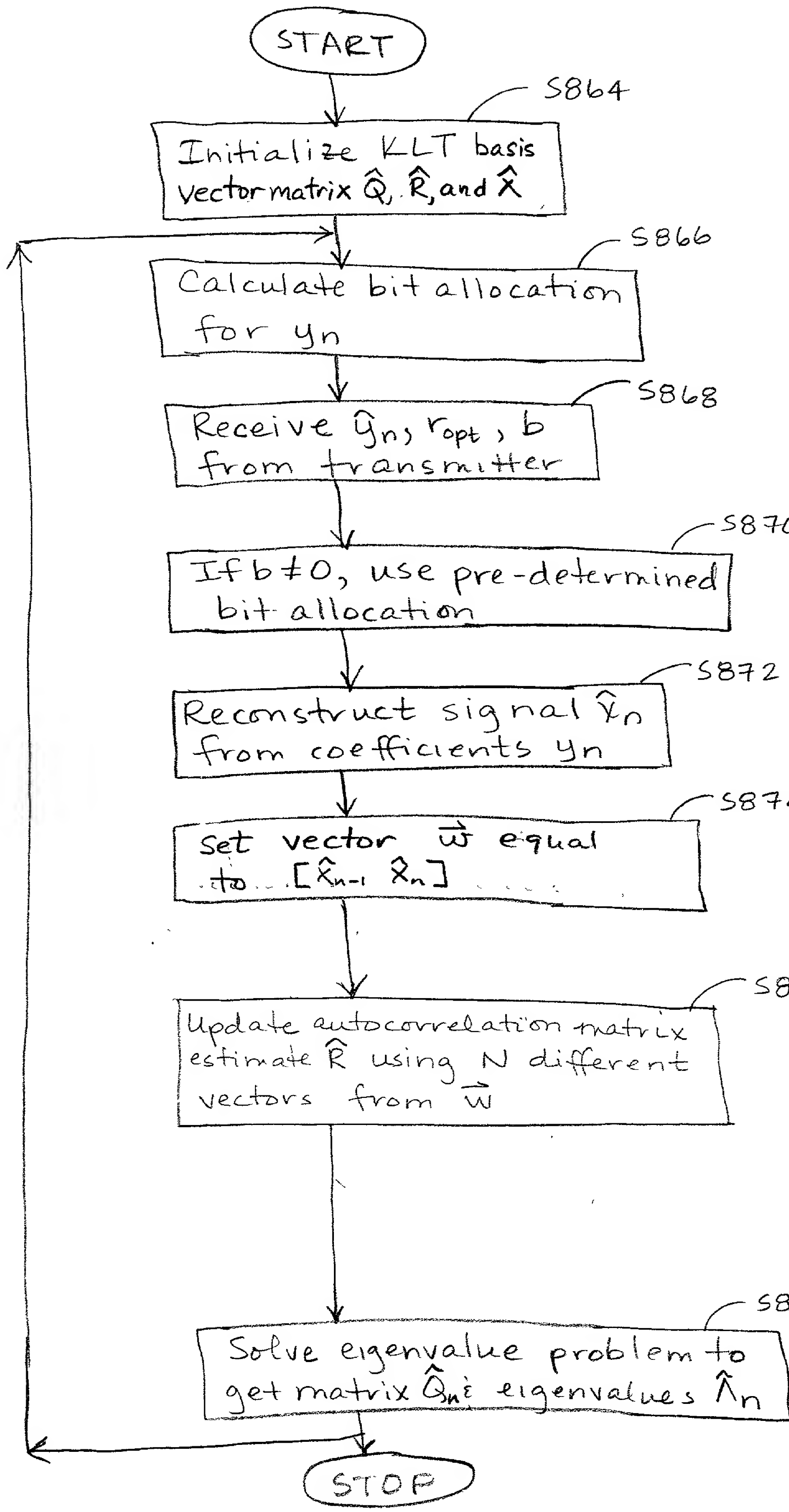

START
S864
Initialize KLT basis vector matrix $\hat{Q}$, $\hat{R}$, and $\hat{X}$
S866
Calculate bit allocation for y_n
S868
Receive $\hat{y}_n$, r_{opt}, b from transmitter
S870
If b≠0, use pre-determined bit allocation
S872
Reconstruct signal $\hat{x}_n$ from coefficients y_n
S874
Set vector $\vec{w}$ equal to $[\hat{x}_{n-1} \; \hat{x}_n]$
S882
Update autocorrelation matrix estimate $\hat{R}$ using N different vectors from $\vec{w}$
S886
Solve eigenvalue problem to get matrix $\hat{Q}_n$ & eigenvalues $\hat{\Lambda}_n$
STOP

Fig 8B

Figure 8C

transmitter

$\hat{Q}_0 = I_N$
$\hat{X}_0 = \underline{0}$
$\hat{R}_0 = \beta I_N$
for $n = 1, 2, \ldots$
  $y_n = \hat{Q}_{n-1}^T x_n$
  $\hat{y}_n = \Delta(y_n)$
  $\rho = 1,\ K = 1,\ b = 0$
  while $\rho > MSE_{max}$ and $b < 2$
    $\hat{x}_n = \hat{Q}_{n-1}(:, 1{:}K)\,\hat{y}_n(1{:}K)$
    $\rho = \|\hat{x}_n - x_n\|^2$
    $k = k + 1$
    if $k = N + 1$ and $\rho > MSE_{max}$
      use alternative bit allocation
      $b = b + 1,\quad k = 1$
      $y_n = \hat{Q}_{n-1}^T x_n$
      $\hat{y}_n = \Delta(y_n)$
    end
  end
  if $b \neq 2$, $r_{opt} = k - 1$
  if $b = 2$
    $r_{opt} = N$
    reduce r_{opt} until $\hat{y}_n(r_{opt}) \neq 0$
  end
  transmit $\hat{y}_n(1{:}r_{opt})$, r_{opt}, b to receiver
  $w_n = [\hat{x}_{n-1}^T \ \ \hat{x}_n^T]^T$
  $\hat{R}_{n-1,0} = \hat{R}_{n-1}$
  for $m = 1, \ldots N$
    $z = w_n(m+1 : m+N)$
    $\hat{R}_{n-1,m} = \gamma \hat{R}_{n-1,m-1} + z z^T$
  end
  $\hat{R}_n = \hat{R}_{n-1,N}$
  solve $\hat{R}_n \hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$
end

receiver

$\hat{Q}_0 = I_N$
$\hat{X}_0 = \underline{0}$
$\hat{R}_0 = \beta I_N$
for $n = 1, 2, \ldots$
  wait for $\hat{y}_n$, r_{opt}, and b
  if $b \neq 0$, use alternative bit allocation
  $\hat{x}_n = \hat{Q}_{n-1} \hat{y}_n$
  $w_n = [\hat{x}_{n-1}^T \ \ \hat{x}_n^T]^T$
  $\hat{R}_{n-1,0} = \hat{R}_{n-1}$
  for $m = 1 : N$
    $z = w_n(m+1 : m+N)$
    $\hat{R}_{n-1,m} = \gamma \hat{R}_{n-1,m-1} + z z^T$
  end
  $\hat{R}_n = \hat{R}_{n-1,N}$
  solve $\hat{R}_n \hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$
end

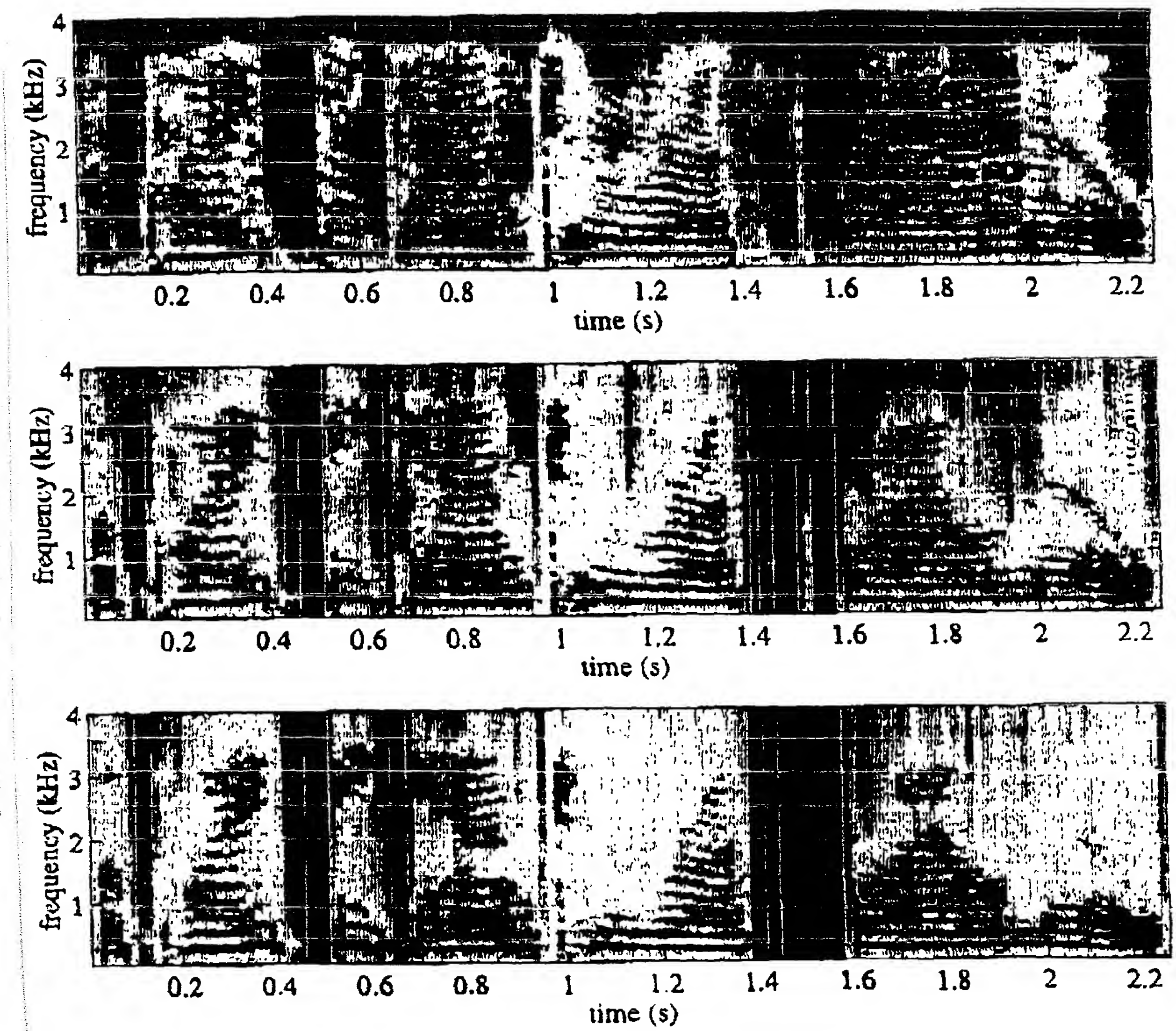


Fig 9

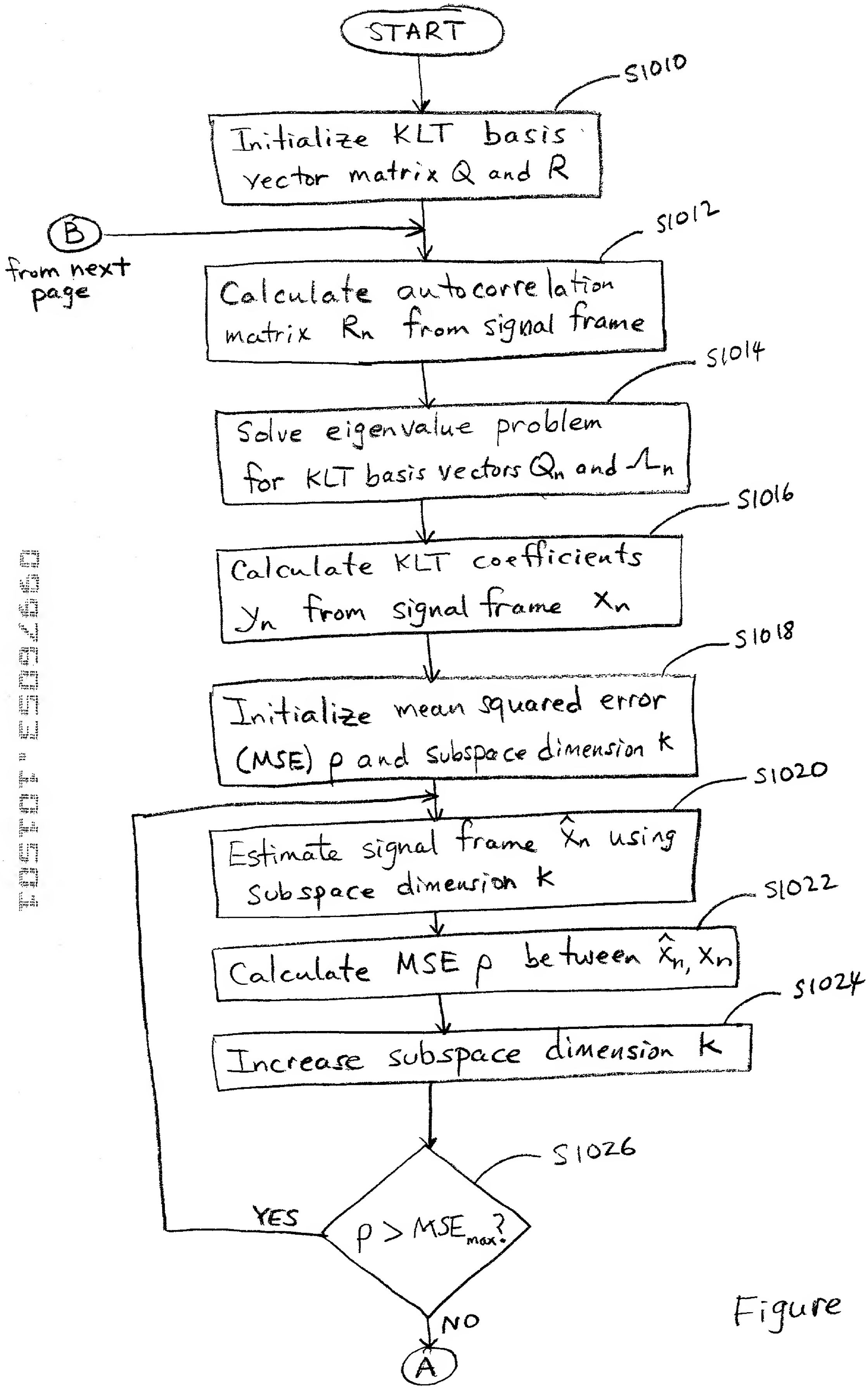

START
S1010
Initialize KLT basis vector matrix Q and R
B
from next page
S1012
Calculate autocorrelation matrix R_n from signal frame
S1014
Solve eigenvalue problem for KLT basis vectors Q_n and Λ_n
S1016
Calculate KLT coefficients y_n from signal frame x_n
S1018
Initialize mean squared error (MSE) ρ and subspace dimension k
S1020
Estimate signal frame $\hat{x}_n$ using subspace dimension k
S1022
Calculate MSE ρ between $\hat{x}_n, x_n$
S1024
Increase subspace dimension k
S1026
$\rho > MSE_{max}$?
YES
NO
A

Figure 10A

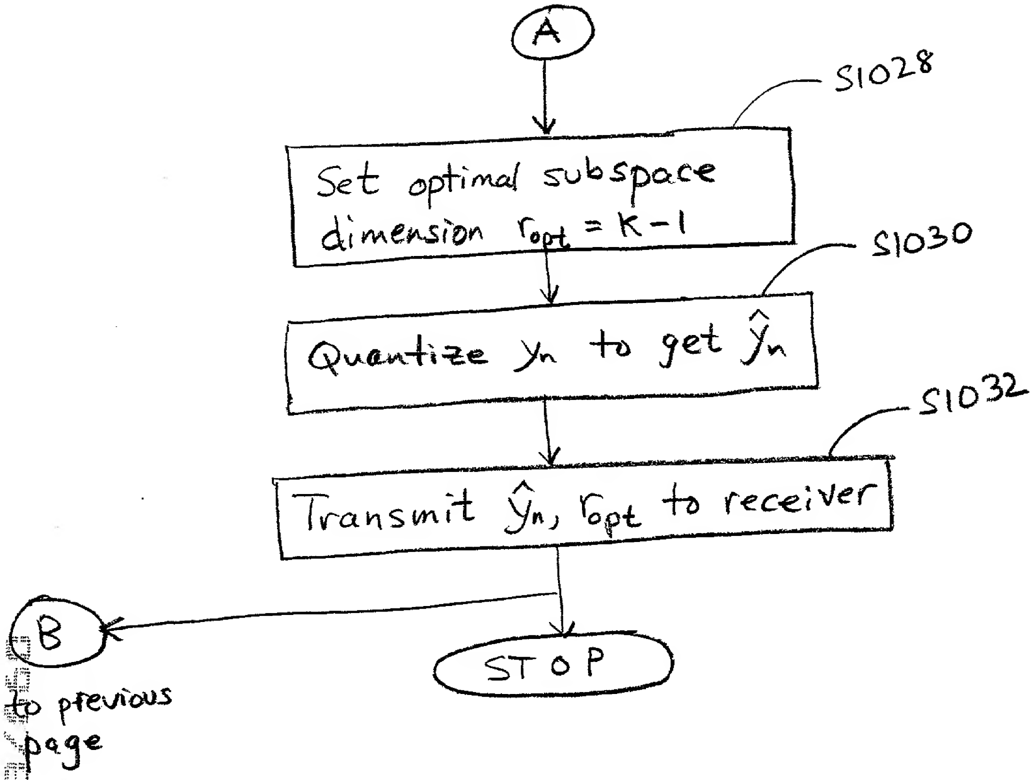


Figure 10A (cont.)

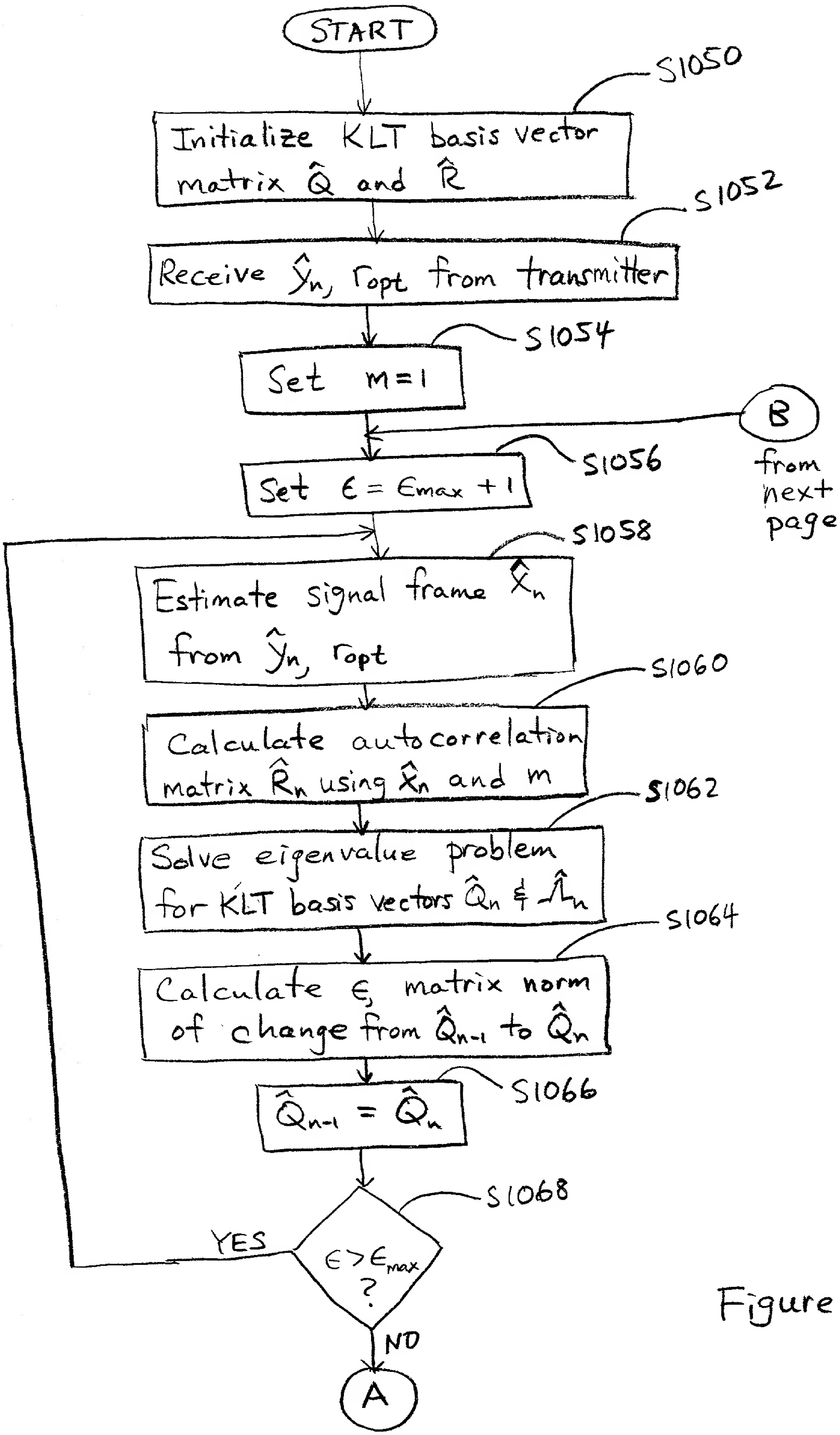

START
S1050
Initialize KLT basis vector matrix $\hat{Q}$ and $\hat{R}$
S1052
Receive $\hat{y}_n$, r_{opt} from transmitter
S1054
Set m=1
B
from next page
S1056
Set $\epsilon = \epsilon_{max} + 1$
S1058
Estimate signal frame $\hat{x}_n$ from $\hat{y}_n$, r_{opt}
S1060
Calculate autocorrelation matrix $\hat{R}_n$ using $\hat{x}_n$ and m
S1062
Solve eigenvalue problem for KLT basis vectors $\hat{Q}_n$ & $\hat{\Lambda}_n$
S1064
Calculate ϵ, matrix norm of change from $\hat{Q}_{n-1}$ to $\hat{Q}_n$
S1066
$\hat{Q}_{n-1} = \hat{Q}_n$
S1068
$\epsilon > \epsilon_{max}$?
YES
NO
A

Figure 10B

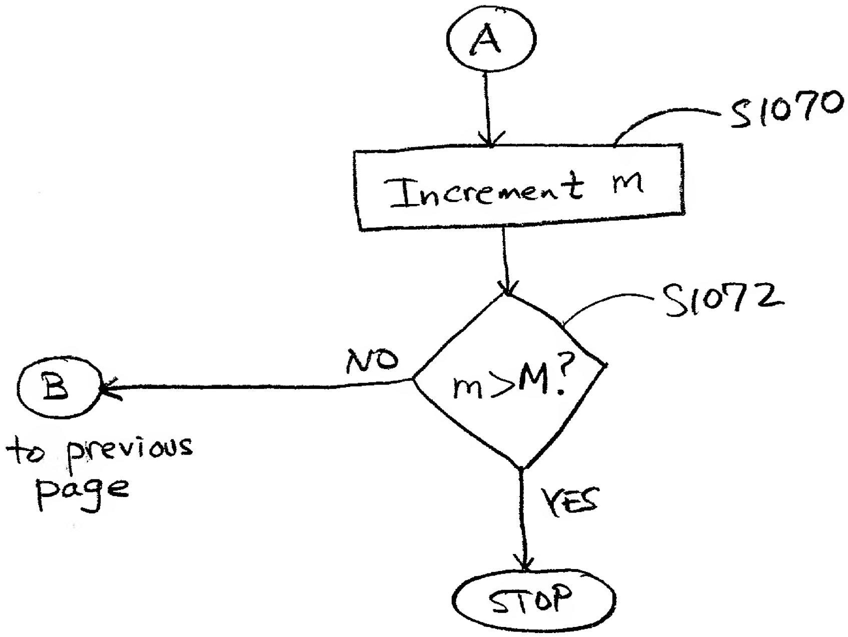


Figure 10B (cont.)

transmitter

$Q_0 = I_N$

$R_0 = \beta I_N$

for $n = 1, 2, \ldots$

    $R_n = \gamma R_{n-1} + x_n x_n^T$

    solve $R_n Q_n = Q_n \Lambda_n$ for Q_n, Λ_n

    $y_n = Q_n^T x_n$

    $\rho = 1$

    $k = 1$

    while $\rho > MSE_{max}$

        $\hat{x}_n = Q_n(:, 1:k)\, y_n(1:k)$

        $\rho = \|\hat{x}_n - x_n\|^2 / \|x_n\|^2$

        $k = k + 1$

    end

    $r_{opt} = k - 1$

    $\hat{y}_n = \Delta(y_n)$

    transmit $\hat{y}_n, r_{opt}$ to receiver

end

receiver

$\hat{Q}_0 = I_N$

$\hat{R}_0 = \beta I_N$

for $n = 1, 2, \ldots$

    wait for $\hat{y}_n, r_{opt}$

    $\alpha = 1/M$

    for $m = 1, .., M$

        $\epsilon = \epsilon_{max} + 1$

        while $\epsilon > \epsilon_{max}$

            $\hat{x}_n = \hat{Q}_{n-1}(:, 1:r_{opt})\, \hat{y}_n(1:r_{opt})$

            if $m = 1$

                $\hat{R}_n = \gamma \hat{R}_{n-1} + \alpha \hat{x}_n \hat{x}_n^T$

            else

                $\hat{R}_n = \hat{R}_n + \alpha \hat{x}_n \hat{x}_n^T$

            end

            solve $\hat{R}_n \hat{Q}_n = \hat{Q}_n \hat{\Lambda}_n$ for $\hat{Q}_n, \hat{\Lambda}_n$

            $\epsilon = \|\hat{Q}_n - \hat{Q}_{n-1}\|$

            $\hat{Q}_{n-1} = \hat{Q}_n$

        end

    end

end

Figure 10c

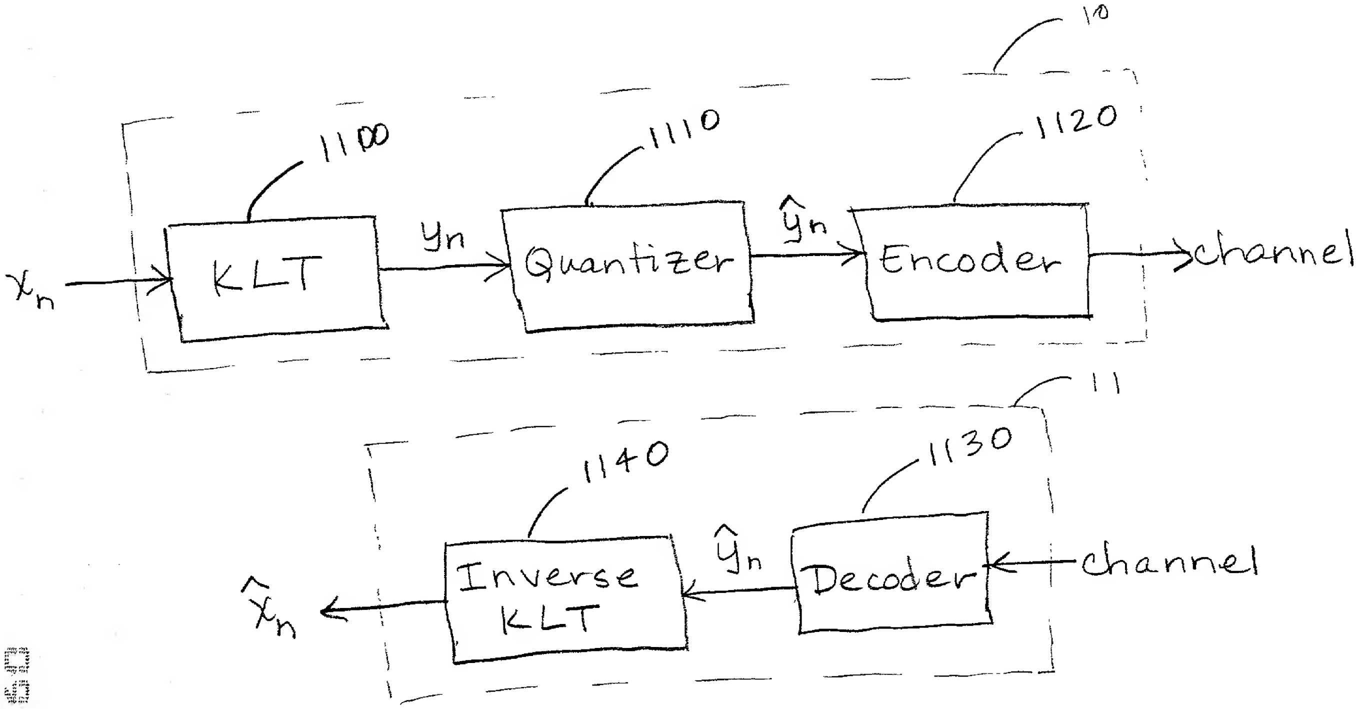

10
1100
1110
1120
x_n
KLT
y_n
Quantizer
$\hat{y}_n$
Encoder
channel
11
1140
1130
Inverse KLT
$\hat{y}_n$
Decoder
channel
$\hat{x}_n$

Fig. 11